Lucky Imaging

on Deep Sky Objects

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We will see...
how to apply Lucky Imaging, a consolidated technique used in planetary imaging, to Deep Sky Objects.

We will not see...
beautiful pictures, instead just some experimentation results.
Main Topics

Imaging DSO ➤ *Traditional techniques*

Turbulence and Seeing ➤ *problems to face*

Deconvolution & Adaptive Optics ➤ *one solution*

Lucky Imaging ➤ *another possible solution*

EMCCD Cameras ➤ *new cameras*

DSO Lucky Imaging with EMCCD ➤ *new pipeline*
Imaging Deep Sky Objects

DSO are usually very faint objects

They require long integration time

Multiple imaging parameters must be taken into account (*guiding, flexatures, focusing, etc.*)

Small and Medium Focal Lenghts are mostly used
Turbulence and Seeing [1/2]

Twinkle twinkle little star...
Turbulence and Seeing [2/2]

Turbulence model is quite complex

Metric is typically based on Isoplanatic Patches

Turbulence distortion is almost proportional to telescope aperture

Turbulence moves targets in 3 directions (X-Y-Z)
Deconvolution – *Blur Model*

A distorted image ($I_d$) could be described as:

$$I_d = O_d * I_o + N$$

where $N$ is the noise introduced by the Image sampling, $O_d$ the distortion operator, $I_o$ the original source signal.

*Finding the Inverse Operator*

$$I_d - N = O_d * I_o$$

$$I_o = O_d^{-1} * (I_d - N)$$
Deconvolution - *Finding the right operator*

\[ O_d \quad \rightarrow \quad O_d^{-1} \]

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Adaptive Optics \([1/2]\)

Adaptive Optics Schematics (source answers.com)
Adaptive Optics [2/2]

Tip Tilt (X-Y) AO are available to amateurs:

- High freqs (30Hz) need a bright reference star
- Cannot overcome the focus (Z) components

Regarding professionals, only few observatories have an Adaptive Optics System (X-Y-Z) with LGS (Laser Guide Star) that permits to reach (500-1000 Hz) very fast updates.
Lucky Imaging

Lucky Imaging is a commonly used technique by amateurs for planetary pictures.

- High frequencies sampling (30-60 Hz)
- Selection of best frames (around 10%)
Lucky Imaging – Pros vs Cons

**Pros**

- Overcome major turbulence effects
- Quite independent from tracking issues

**Cons**

- Needs a very bright source
- Could be field limited, usually by the Isoplanatic Patch size
EMCCD Camera [1/3]

EMCCD = Electron Multiplied CCD

Multiplication Stage inside the CCD

\[
\text{CCD\_Gain\_100X} = 100\times\text{CCD\_Signal} + 100\times\text{CCD\_Noise}
\]

\[
\text{EMCCD\_Gain\_100X} = 100\times\text{EMCCD\_Signal} + \text{EMCCD\_Noise}
\]
EMCCD Camera [2/3]

EMCCD Workflow (source andor.com)
EMCCD Camera [3/3]

EMCCD Impact Ionization (source photonics.com)
DSO Lucky Imaging with EMCCD [1/10]

Main goals

Sampling pictures on some DSO

Use of Long Focal Lengths (around 8 mt)

Finding the right software pipeline

Making a comparison between CCD and EMCCD
DSO Lucky Imaging with EMCCD [2/10]

**Camera Info**

**Andor Luca-S**

- **Pixel Size:** 10 microns
- **EMCCD Array:** 658x496 with ROI
- **A/D conversion:** 14bit
- **Cooling:** -20°C
- **Framerate:** up to 37 fps
- **Connection:** USB 2
- **QE:** around 50%
- **EMCCD Gain:** up to 1000x

Lucky Imaging on Deep Sky Objects
DSO Lucky Imaging with EMCCD [3/10]

Imaging System (*Paramount ME + C14 + Andor Luca-s*)
DSO Lucky Imaging with EMCCD [4/10]
DSO Lucky Imaging with EMCCD [5/10]
DSO Lucky Imaging with EMCCD [6/10]
DSO Lucky Imaging with EMCCD [7/10]

\[ fl=7900 \text{mm} \, f/22 \, 800 \text{ frames} @ 60\text{ms} \]
DSO Lucky Imaging with EMCCD [8/10]

M 53, C14 f=7900mm f/22 Preliminary Results
Comparison between standard CCD and EMCCD

800 Frames selected from 2000
Single Frame exposure: 60ms (1/17 sec)
Total exposure: 48 sec
Andor Luca

120 Frames selected from 232
Single Frame exposure: 5 sec
Total exposure: 600 sec
Standard CCD
DSO Lucky Imaging with EMCCD [9/10]

M53 Sampling Video
DSO Lucky Imaging with EMCCD [10/10]

Some results on M13 obtained using an EMCCD on the 5 meters @ Palomar Observatory (source Univ. Of Cambridge, Lucky Imaging Group)
Possible applications and Next Steps

Sampling fast images of Pulsar
Use of the EMCCD as guide cameras for AO

Camera cooldown up to -100°C (-80°C by TE)
Smarter software pipelines
We got Lucky!

**Relocation:** *Remote working, Local Telescope*  
**vs**  
**Remote Imaging:** *Local working, Remote Telescope*
References

LuckyCam Group:
http://www.ast.cam.ac.uk/research/lucky

Some Camera manufacturers:
www.andor.com
www.emccd.com
Thank you!